

Sivers effect in semi-inclusive DIS and in the Drell-Yan Process

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Outline

- Brief overview of the theory
- Fit of the Sivers function in semi-inclusive DIS
- Prediction for Drell-Yan
- Summary and discussion

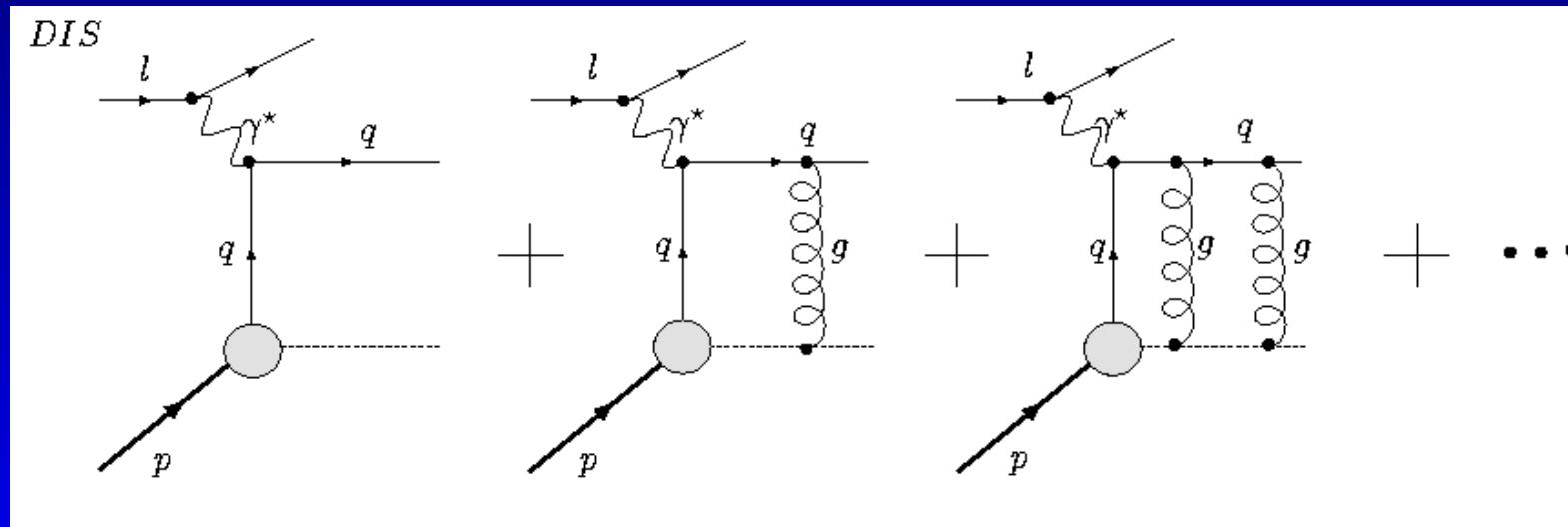
Correlator of inclusive DIS

partons move collinear with the hadron

$$\text{Quark-quark correlator} \quad \Phi(x) = \int \frac{d\xi^-}{2\pi} e^{ik^+ \xi^-} \langle P | \bar{\Psi}(0) \mathcal{W} \Psi(\xi^-) | P \rangle$$

\mathcal{W} is the Gauge-Link which guarantees the gauge-invariance of the correlator.

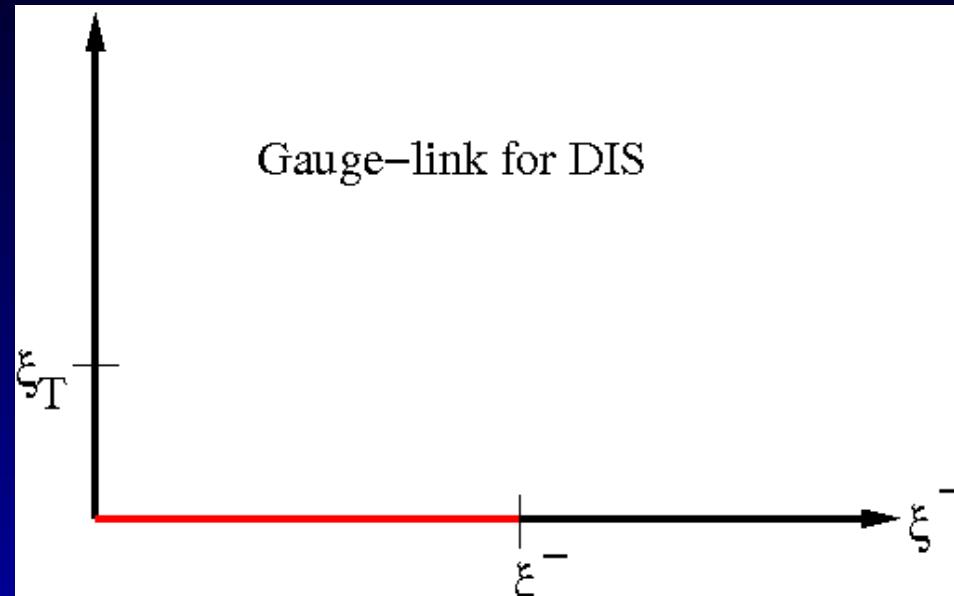
$$\text{Definition} \quad \mathcal{W}(x, y) = \mathcal{P} \left(\exp \left(\int_x^y d\alpha^\mu A_\mu(\alpha) \right) \right)$$



Gauge-Link

$$\Rightarrow \int_0^{\xi^-} d\alpha^- A^+(\alpha) = 0$$

=0 in light-cone gauge



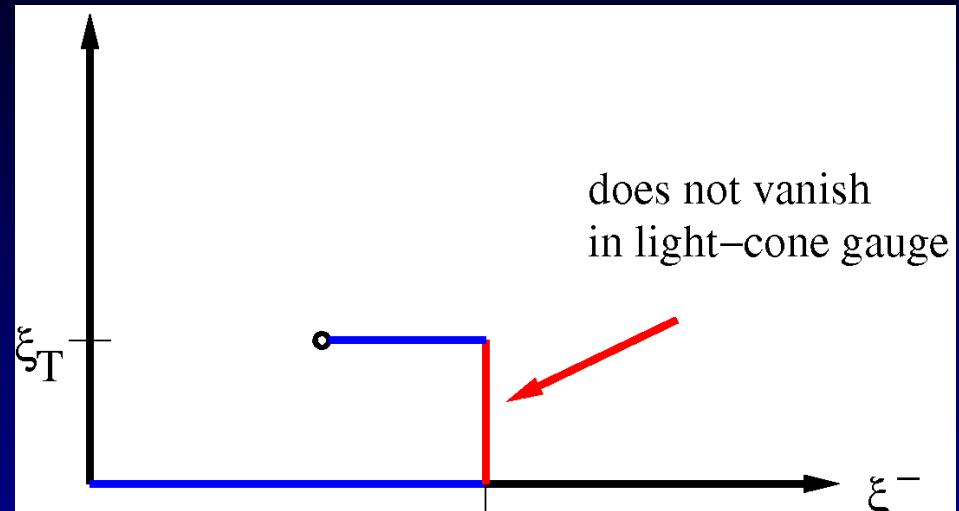
$$\frac{1}{2} Tr (\Phi \gamma^+) = \int \frac{d\xi^-}{4\pi} e^{ik^+ \xi^-} < P | \bar{\Psi}(\xi^-) \gamma^+ \Psi(0) | P > = f_1(x)$$

where

$$x = \frac{P_{parton,||}}{P_{hadron,||}}$$

Sivers function

allow transverse momentum
⇒ there is no gauge in which
the gauge-link can be
neglected



⇒ one gets two extra, transverse momentum dependent parton distribution functions f_{1T}^\perp and h_1^\perp . E.g.

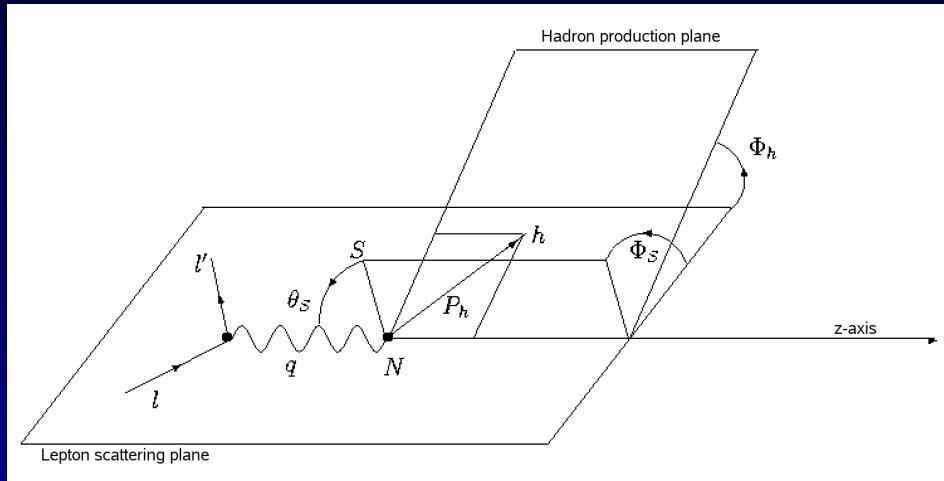
$$\frac{1}{2} Tr (\Phi \gamma^+) = \int \frac{d^2 \vec{\xi}_\perp d\xi^-}{2(2\pi)^3} e^{i(k^+ \xi^- - \vec{k}_\perp \cdot \vec{\xi}_\perp)} \langle P | \bar{\Psi}(0) \mathcal{W} \gamma^+ \Psi(0, \xi^-, \vec{\xi}_\perp) | P \rangle$$

$$= f_1(x, \vec{k}_\perp) - \frac{\varepsilon_{\rho\sigma}^\perp k_\perp^\rho S_\perp^\sigma}{M} f_{1T}^\perp(x, \vec{k}_\perp)$$

Brodsky, Hwang, Schmidt (2002), Collins (2002)

Sivers asymmetry

non-zero Sivers function → expect azimuthal single-spin asymmetry



Semi-inclusive DIS

$$Q^2 = -q^2 = -(l - l')^2$$

$$s = (l + P)^2$$

$$x = \frac{Q^2}{2P \cdot q}$$

$$y = \frac{P \cdot q}{P \cdot l}$$

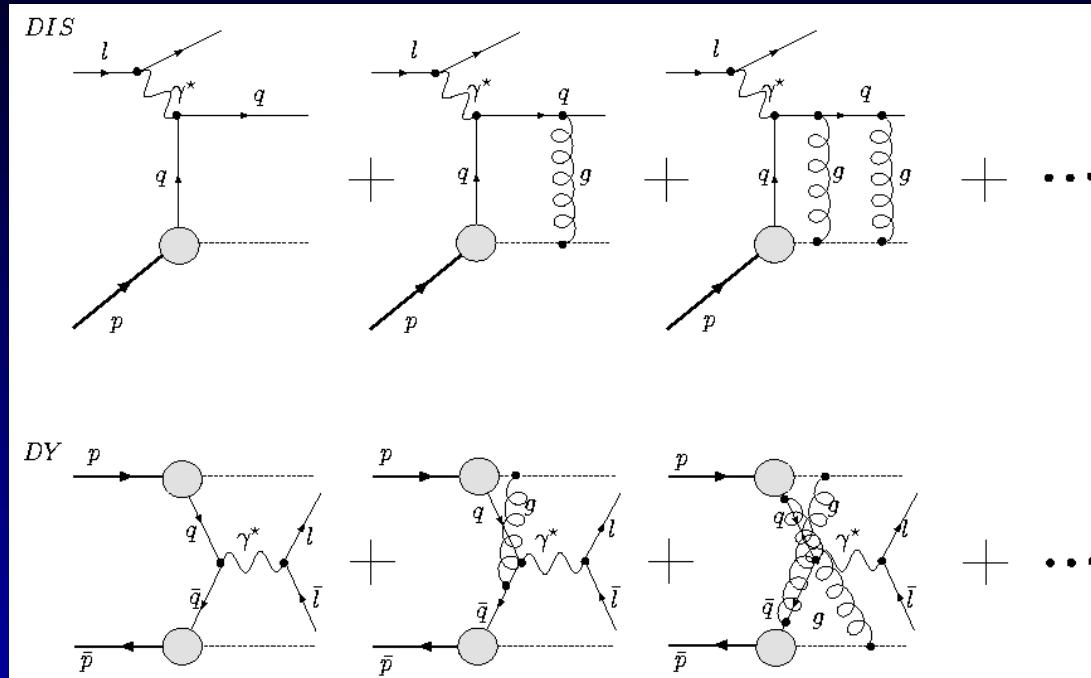
$$z = \frac{P \cdot P_h}{P \cdot q}$$

$$\begin{aligned} A_{UT}^{\left\langle \frac{P_{hT}}{M} \right\rangle} \sin(\phi_h - \phi_s) &= \\ -2 |\vec{s}_\perp| \frac{\sum_f e_f^2 \int_{cuts} dz z D_{1,f}(z) x f_{1T,f}^{\perp(1)}(x)}{\sum_f e_f^2 \int_{cuts} dz D_{1,f}(z) x f_{1,f}(x)} \end{aligned}$$

$$\begin{aligned} f_{1T}^{\perp(1)}(x) &= \\ \int d^2 \vec{k}_\perp \frac{\left(\vec{k}_\perp\right)^2}{2M^2} f_{1T}^\perp(x, \vec{k}_\perp) \end{aligned}$$

first Sivers moment

Gauge-link and time-reversal

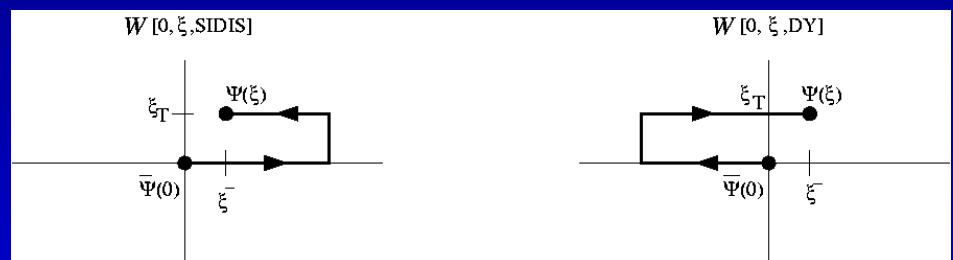


The gluon exchange in semi-inclusive DIS takes place after the hard scattering, whereas in DY it takes place before.

The path of integration is reversed in this case:

This means that

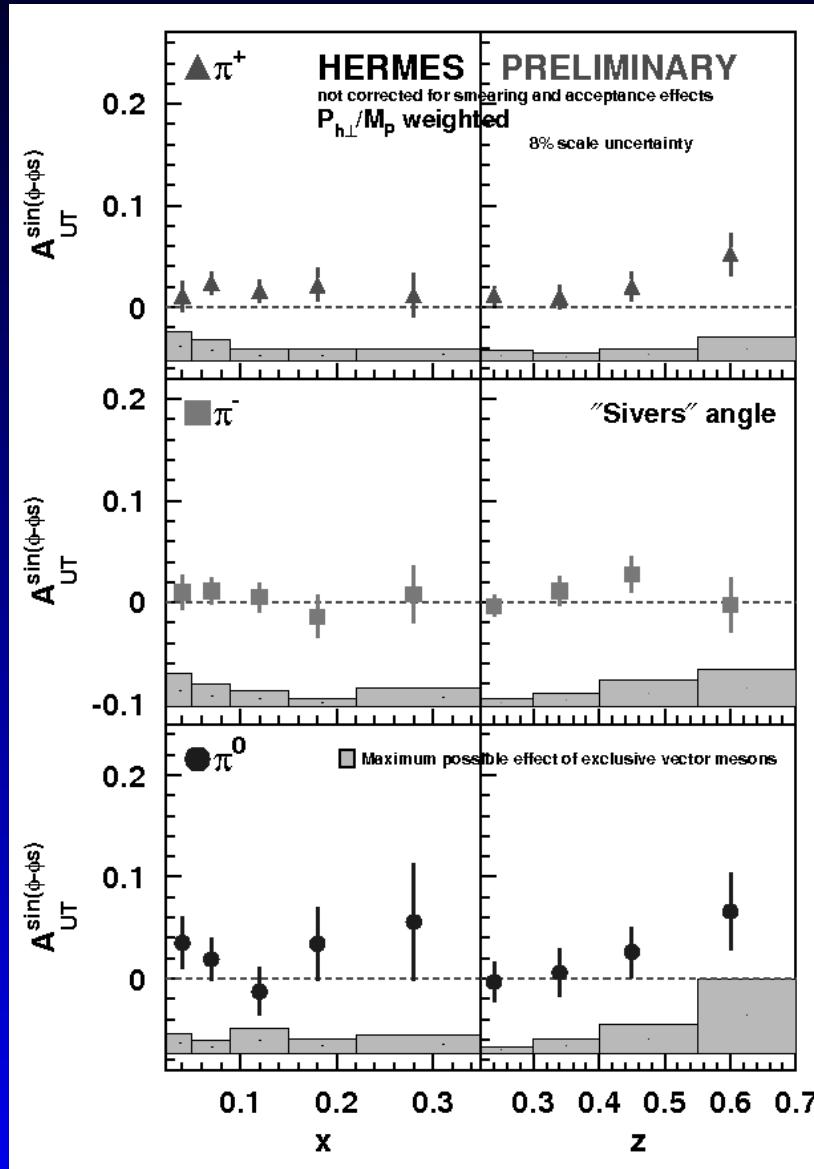
$$\mathcal{T}^{-1} \mathcal{W}_{SIDIS} \mathcal{T} = \mathcal{W}_{DY}$$



From that one can conclude (Collins, 2002)

$$f_{1T, SIDIS}^\perp = -f_{1T, DY}^\perp$$

HERMES data



e.g. R.Seidl DIS2004

use weighted data

→ model independent

→ Sudakov effects

might cancel

Fit of HERMES data

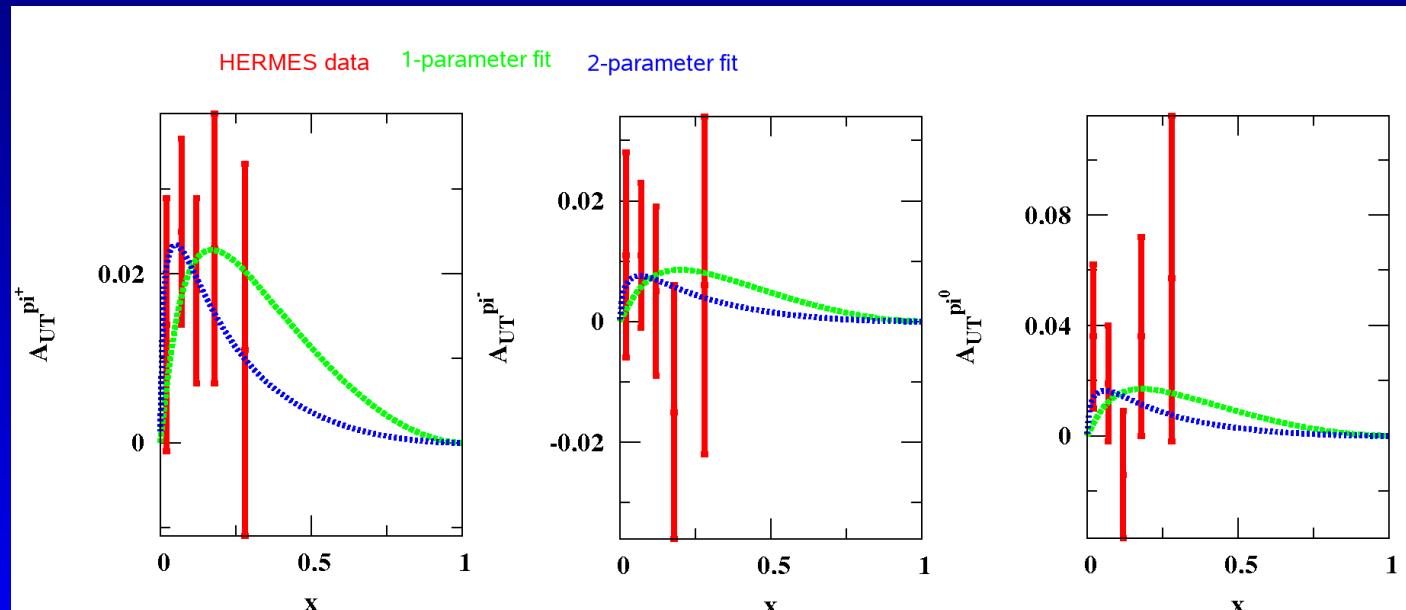
- neglecting strange and antiquarks distributions of the Sivers function
- Large- N_C limes of QCD:

$$f_{1T}^{\perp(1),u} = -f_{1T}^{\perp(1),d}$$
- Ansatz for the fit:

$$xf_{1T}^{\perp(1)} = ax^b(1-x)^5$$
- 1-Parameter fit:

$$xf_{1T}^{\perp(1),u} = -0.4x(1-x)^5$$
- 2-Parameter fit:

$$xf_{1T}^{\perp(1),u} = -0.1x^{0.3}(1-x)^5$$



Comment on Ansatz

with the ansatz $f_{1T}^{\perp(1),u} = -f_{1T}^{\perp(1),d}$ the sum rule

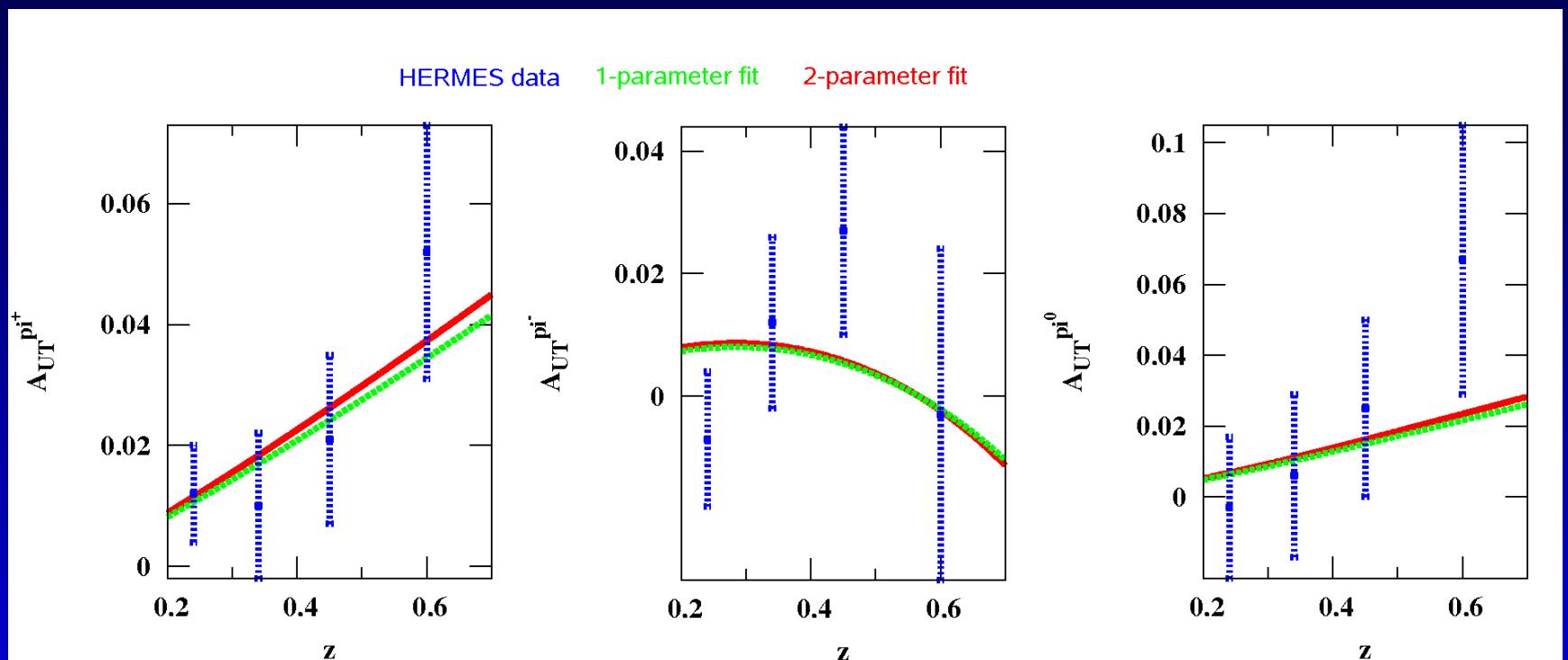
$$\sum_{f=g,u,d\dots} \int dx f_{1T}^{\perp(1),f}(x) = 0$$

is automatically fulfilled

Burkardt, 2003

Comparison to $A_{UT}(z)$

A check of the fit can be done by a comparison to the z-dependent data

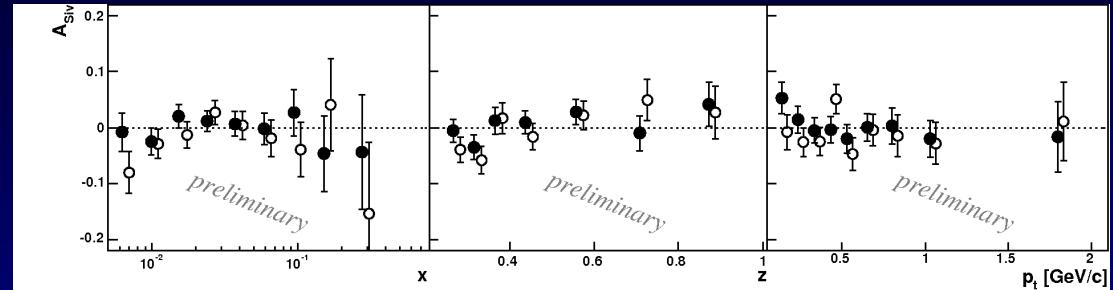


Comments on fit

because of the large- N_c relation

$$f_{1T}^{\perp(1),u} = -f_{1T}^{\perp(1),d}$$

the Sivers asymmetry measured with a deuterium target is expected to be small



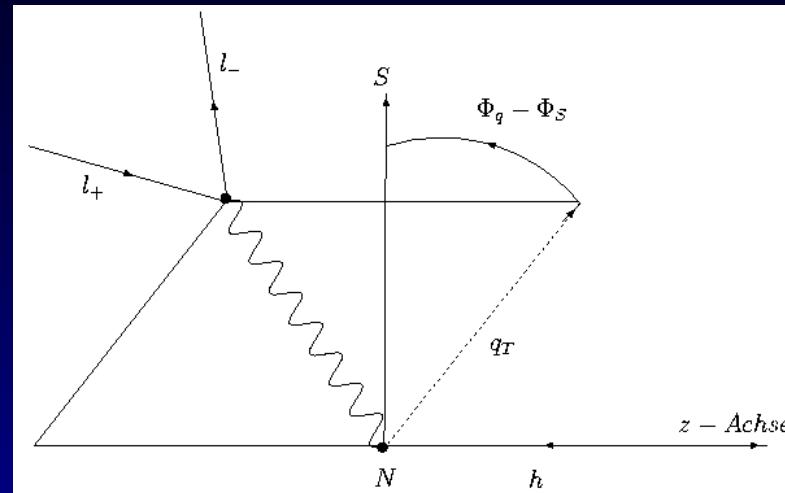
COMPASS: hep-ex 0411076

The parametrization of the Sivers function we get with the large- N_C relation is comparable to the one of Anselmino et al. (hep-ph/0501196) based on the unweighted data.

Prediction for Drell-Yan

$$x_1 = \frac{Q^2}{2P_1 \cdot q}$$

$$x_2 = \frac{Q^2}{2P_2 \cdot q}$$



$$A_{UT}^{\left\langle \frac{q_T}{M} \right\rangle \sin(\phi_q - \phi_s)}(x_1, x_2) = -2 |\vec{s}_\perp| \frac{\sum_f e_f^2 x_1 f_{1T}^{\perp(1)f/p}(x_1) x_2 f_1^{f/h}(x_2)}{\sum_f e_f^2 x_1 f_1^{f/p}(x_1) x_2 f_1^{\bar{f}/h}}$$

- The prediction is based on

$$f_{1T, SIDIS}^\perp = -f_{1T, DY}^\perp$$

Prediction for Drell-Yan

PAX

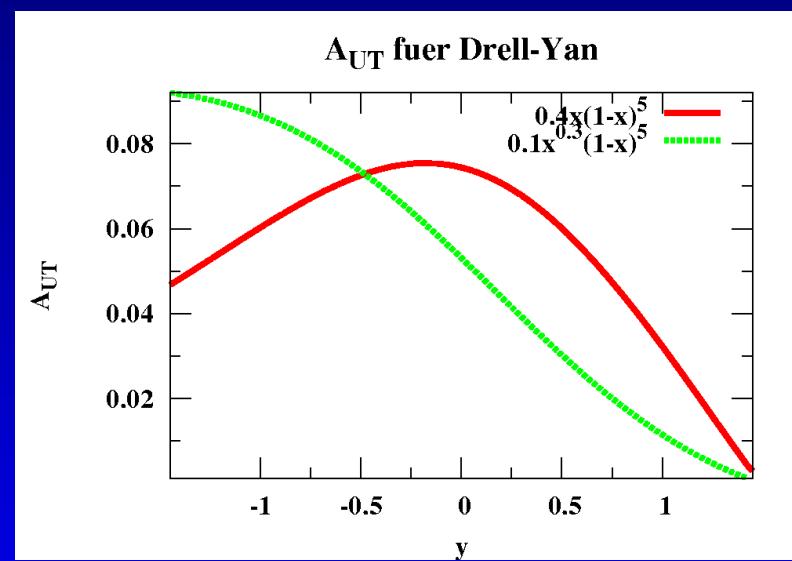
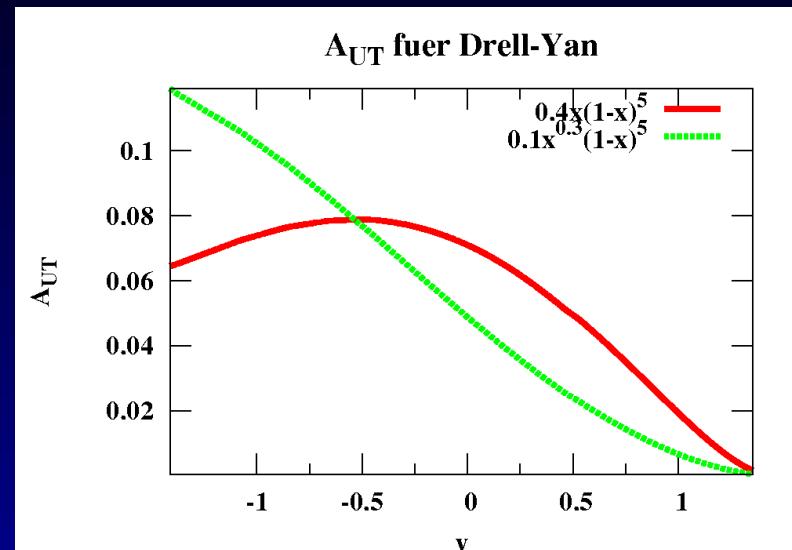
$$Q^2 = 2.5 \text{ GeV}^2$$

$$s = 45 \text{ GeV}^2$$

COMPASS

$$Q^2 = 20 \text{ GeV}^2$$

$$s = 400 \text{ GeV}^2$$



Asymmetry is of the order of 5-10% !

Summary and discussion

Fit

- A parameterization of the Sivers function could be extracted from the weighted HERMES data
- Based on this parameterization one can describe the z-dependent HERMES data well
- The exponent of the factor $(1 - x)$ is not well defined by the data
⇒ hope for more data at larger x
- The parameterization is comparable to Anselmino et al.
(hep-ph/0501196)

Summary and discussion

Prediction for Drell-Yan

- Based on the present understanding of the Sivers function a prediction for the Sivers asymmetry in the experiments PAX and COMPASS has been made.
- The predicted asymmetry is of the order of 5-10%
⇒ measurable !
- Data of the Drell-Yan Sivers asymmetry should show if the present QCD understanding of this observable is correct